

COMPATIBILITY OF AIRCRAFT AND SHIPBORNE INSTRUMENTS USED IN AIR-SEA INTERACTION RESEARCH

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ABSTRACT

On June 16, 1966, an experiment was performed off the east coast of Florida that involved two research aircraft, one from the Naval Oceanographic Office and one from ESSA's Research Flight Facility, and the USCGSS *Peirce*, aboard which were two scientists from ESSA's Sea Air Interaction Laboratory, and the Weather Bureau Airport Station at Jacksonville, Fla. The purpose of this investigation was to determine the comparability of data for air-sea interaction research as determined by aircraft temperature, humidity, pressure, and wind sensors; airborne IR radiometers; a tethered boundary layer instrument package, radiosondes, rawinsondes, and dropsondes. Results showed generally good agreement (within listed instrumental accuracies) between comparisons of aircraft and radiosonde temperature and humidity observations, fair agreement of wind observations, and very poor comparisons between dropsondes and radiosondes. The sea surface temperature readings obtained by the airborne radiation thermometer aboard the Navy aircraft were well within $\pm 0.4^\circ$ C. operational accuracy of the instrument when compared with bucket temperature measurements taken aboard the *Peirce*. Whether the accuracies of these presently available instruments are good enough for mesoscale and macroscale ocean-atmosphere interaction investigations now being planned will have to await studies of the environments in which these experiments will take place.

1. INTRODUCTION

A major, comprehensive, field investigation is now being planned by ESSA, the primary focus of which will be on the problem of ocean-atmosphere interaction, as well as related topics in physical oceanography and microscale and mesoscale meteorology. The primary objectives of this experiment are: 1) to study the total fluid environment within a limited area, and 2) to provide a realistic pilot field study for the planning and execution of a succeeding major Tropical Ocean Area Study within the framework of the World Weather Watch.

The plans for this experiment call for among other things the deployment of several ships on fixed stations several hundred miles apart, a roving ship for making meteorological and oceanographic measurements within the study area, and several research aircraft that will be used in a variety of measurement programs, such as vertical profiling, making line integral observations, and obtaining sea surface and subsurface temperature data. Further, these plans call for the utilization of ship launched rawinsondes, for obtaining vertical soundings of temperature, pressure, humidity, and winds; tethered boundary layer instrument packages for obtaining both profiles of temperature, humidity, pressure, and winds and the time variation of these quantities at any height up to 2000 m.; and air released dropsondes for obtaining vertical profiles of temperature, humidity, and pressure.

Before the investigation can be initiated, however, there are certain preliminary steps that must be taken. These include: 1) an evaluation of the compatibility of the variety of instruments mentioned above, 2) an improvement in our knowledge of the environment in the region of the experiment, and 3) a test of the major instrument systems in the experimental area. This paper concerns itself with the first of these steps.

In June 1966 an experiment was performed to evaluate the comparability of existing operational instruments of the types planned for use in future mesoscale and macroscale ocean-atmosphere interaction studies. The objectives of this investigation were to observe the comparability of the data obtained by the various methods mentioned above; to ascertain whether observed differences between any two readings of a given parameter were within the quoted accuracies of the measuring instruments, and to arrive at a conclusion regarding the use of these state-of-the-art instruments for air-sea interaction research.

2. INSTRUMENTATION AND DATA ACQUISITION

Because of the nature of this experiment a variety of organizations was called upon to pool their efforts toward accomplishing the mission. The U.S. Naval Oceanographic Office provided the services of its Ocean Aerial Survey Unit of the ASWEPS program and ESSA was represented by the Weather Bureau Airport Station at Jacksonville, Fla., the USCGSS *Peirce*, the Research

Flight Facility (RFF) of the Institute for Atmospheric Sciences, and the Sea Air Interaction Laboratory (SAIL) of the Institute for Oceanography.

The Navy aircraft was a Lockheed Super-G Constellation which, as one of the airborne platforms, was used to obtain measurements of air temperature, pressure, and humidity and sea surface temperature. The air temperature and pressure aboard this aircraft are obtained by a meteorological set (AN/AMQ 17) which consists in part of a platinum wire resistor vortex thermometer and a bellows mechanically linked to a potentiometer. The operational accuracies listed for this device are 0.5°C . for the thermometer and 5 mb. for the pressure sensor.

Humidity data are obtained by an infrared absorption hygrometer system designed and built by the Weather Bureau's Equipment Development Laboratory. Basically this hygrometer is an optical instrument designed to measure the absolute humidity of the atmosphere by measuring the absorption of radiant energy over a given optical path in the spectral region of the infrared water vapor absorption band. A full description of this system is given in [1].

A relatively large console model airborne radiation thermometer (ART) developed by Barnes Engineering Co. is used to obtain sea surface temperature aboard the Navy aircraft. Radiation from the sea surface in the 8 to $13\text{-}\mu$ region is detected by a thermistor bolometer and this received energy, which is proportional to the fourth power of the sea surface temperature, is translated into temperature readings by electronic processing. The operational accuracy of this system is listed as $\pm 0.4^{\circ}\text{C}$.

These instruments represent just three of a large array of devices designed for oceanographic research from the Navy aircraft. A complete description of this aerial platform and its capabilities is given in [2].

ESSA's Research Flight Facility provided this project with a DC-6 aircraft instrumented primarily for hurricane research. This aircraft was used as a platform from which air temperature, pressure, and humidity; wind speed and direction; and sea surface temperatures were obtained and from which dropsondes to measure temperature, pressure, and humidity were released.

An AMQ-8 vortex thermometer system is used aboard the RFF aircraft to measure the free-air temperature in flight. System accuracy is quoted to be 0.5°C . Ambient pressure is measured by a pressure transducer operating on an independent static source.

Humidity is measured by a system identical to that described for the Navy aircraft. An interesting secondary objective of this experiment was to obtain data from which a thorough evaluation of the in-flight capabilities of these two absorption hygrometers could be made. The infrared hygrometer, while used on both aircraft as the primary source of humidity information, is still classed as a special purpose device. It has three outstanding features that make it desirable for use aboard aircraft, high

sensitivity at low water-vapor concentrations, fast speed of response for all water-vapor concentrations, and ability to effect a humidity measurement without altering the sample concentration by either adding or subtracting water or changing the state of any part of the sample.

Wind speed and direction, along with latitude and longitude information, are determined by a Doppler navigation and wind-computing system (APN-82) manufactured by General Precision Laboratories. The Research Flight Facility, from operational experience quotes for this system an accuracy of ± 3 kt. for the wind speed and an error function in degrees of roughly $(150 \div \text{wind speed})$ for wind direction.

The dropsonde system used aboard the RFF DC-6 is a military type (AN/AMT-3) and is used to obtain soundings of temperature, pressure, and humidity from aircraft flight level to the surface. Following launch from the aircraft the instrument descends by parachute at a rate of approximately 1,200 ft./min. During this descent the package transmits measurements of temperature, humidity, and pressure in International Morse Code approximately 12 times a minute, and these transmissions are hand copied aboard the aircraft.

The temperature element consists of a bimetallic strip, the humidity element of several strips of hair; and the pressure element is a double-bellows aneroid cell. RFF experience with this system indicates that pressures determined by this instrument are accurate to within plus or minus 2 mb., and that temperature and humidity data are comparable in accuracy to conventional radiosondes.

To obtain sea surface temperatures the RFF employs a Barnes IT-2 infrared thermometer. In principle this device operates similarly to the ART on the Navy aircraft, being a thermistor bolometer with a spectral bandpass of 8 to $13\text{ }\mu$. Physically, however, the unit is much smaller and can be hand held. The sensing head of the radiometer is mounted in the dropsonde chute of the DC-6. A more detailed description of its operation is given in [3]. The manufacturer lists a resolution of 1°F . and an absolute accuracy of 2°F . for this instrument.

The USCGSS *Peirce* was used as a platform from which scientists from SAIL launched conventional radiosondes, obtained sea surface temperatures for comparison with aircraft infrared-sensed temperatures, and gathered air temperature and humidity data at 1,000-ft. and 500-ft. heights with a boundary layer instrument package being developed in-house. This device, which was in the early stages of development at that time, consisted of a standard 403-mHz. radiosonde package supported at the given heights by a pair of kytoons tethered to the ship. The aneroid switch had been replaced with a small clock switch and this permitted alternate transmission of temperature and relative humidity data to a standard radiosonde receiver-recorder located on the ship. (Subsequent to this experiment a more sophisticated package has been developed by SAIL which can be used to measure and

transmit temperature, humidity, and wind speed data simultaneously to receivers on the ship from any height from the surface to 2000 m. The development of this system is the subject of a forthcoming report now in preparation within the laboratory.)

The Weather Bureau participation in this experiment consisted of a rawinsonde launch from the Airport Station at Jacksonville, Fla. A 1200-gm. balloon was released at this station shortly before the arrival of the aircraft over Jacksonville and was tracked by GMD radar to an altitude of about 32,000 ft. Air temperature, pressure, and humidity, of course, were also obtained on this flight.

On June 16, 1966, under ideal weather conditions the instrument comparison test was performed. The operation, as shown in figure 1, proceeded in the following manner. The two aircraft departed Miami, Fla., about 1345 GMT and proceeded at an altitude of 5,000 ft. to a point north of Cape Kennedy staying a few miles inland at all times. This route was necessitated by a launch from the Cape which had been rescheduled from the prior day. After reaching this point the research aircraft turned eastward, descended to 1,000-ft. altitude and continued on the course shown to the USCGSS *Peirce* while maintaining a separation between them of 2 to 3 mi. Upon arriving at the ship and making an initial pass past the boundary layer instrument package tethered at 1,000 ft. the RFF aircraft began its climb to the 500-mb. level while the Navy aircraft made three additional passes over the *Peirce* before beginning its climb.

After completing the ascent to the desired altitude, personnel aboard the DC-6 released a dropsonde while simultaneously a radiosonde was released from the ship. By the completion of the radiosonde and dropsonde soundings the Navy plane had arrived at the same level as the RFF aircraft, and both planes began a 500-ft./min. spiral descent to 500 ft. where four additional passes were made over the ship. A southwesterly flight path was then followed from the *Peirce* to Jacksonville, Fla. Enroute, the Navy plane flew at an altitude of 1,000 ft. collecting sea surface temperature data while the RFF plane climbed to 15,000 ft. for a second dropsonde release about halfway between the ship and the airport station. After reaching Jacksonville the DC-6 made a short ascent to 18,000 ft. and released a third dropsonde, as indicated in figure 1, while the Constellation was completing its climb from 1,000 ft. to the same height. Both aircraft then made a spiral descent as described before to 1,000 ft. just seaward of the coast and east of Jacksonville. After completing the spiral descent, the Navy Constellation terminated its data acquisition operation and returned to its home base at Patuxent River, Md. The RFF DC-6 proceeded on a southerly course toward its home base at Miami, breaking off data acquisition at Daytona Beach.

3. RESULTS

Figures 2-8 and table 1 present the results of this experiment. A quick glance at these graphs makes it

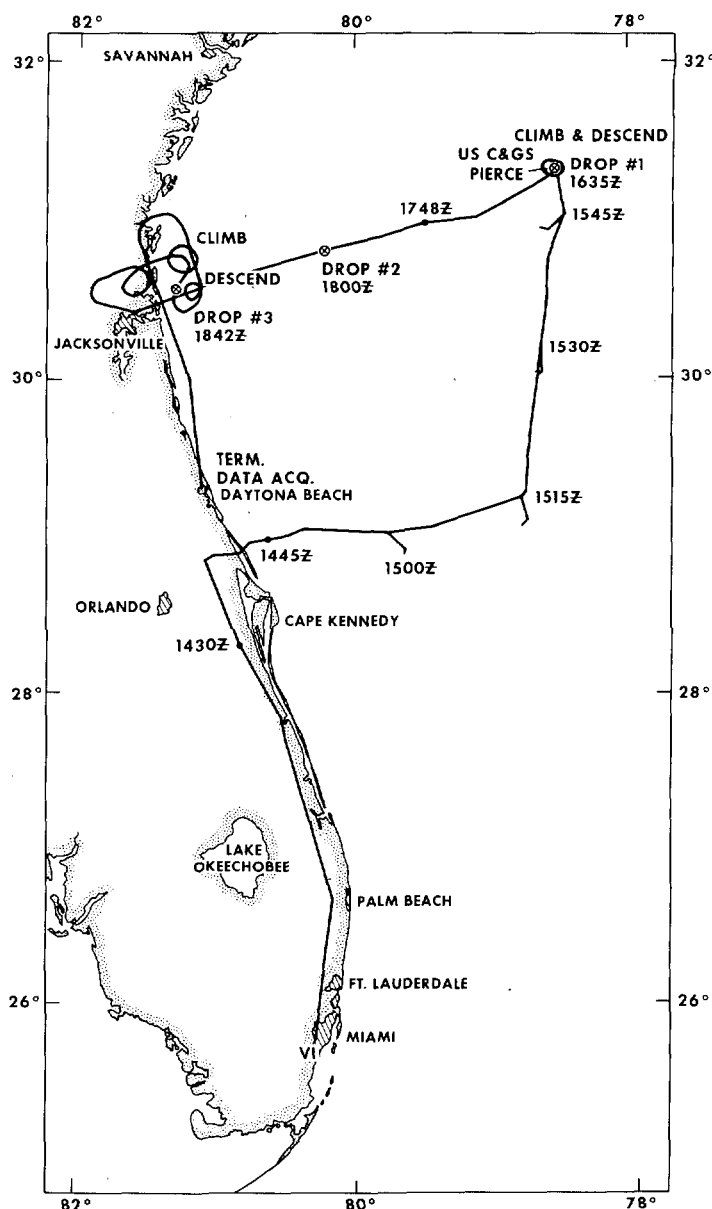


FIGURE 1.—Flight plan of Navy and Research Flight Facility aircraft on June 16, 1966.

TABLE 1.—Comparison of aircraft sensors with boundary layer instrument package and sea surface temperature thermometer

Altitude(ft.)	Air temperature (°C.)			Humidity (gm./m. ³)		Sea surface temperature (°C.)	
	Navy	RFF	Peirce	RFF	Peirce	Navy (ART)	Peirce (Bucket)
1000	24.0	24.0				27.3	27.2
	23.8		24.4	18.3		27.3	27.4
	23.7		24.3	No data		27.3	27.4
	23.7		24.0			27.3	27.3
500	24.6	24.8	25.1	18.5	16.8	27.4	27.3
	24.6	24.8	24.7	18.5	16.1	27.4	27.2
	24.7	24.8	25.0	18.5	15.0	27.4	27.3
	24.7	24.6	25.0	18.5	16.8	27.5	27.3

immediately apparent that there are no data for some of the instruments originally planned to be used and described in the previous section. Unfortunately, there were equipment malfunctions during the flight and even more unfortunate no back-up systems for substitution. This will be discussed further, later.

Figure 2 depicts sea surface temperatures measured by the ART on the Navy plane and a plane-to-plane comparison of air temperatures on the Cape Kennedy-to-ship leg of the flight. As mentioned earlier the lateral separation between the two aircraft was 2 to 3 mi. which possibly could account for some of the observed differences (maximum 0.5°C .) in the air temperature record.

Perhaps the greatest interest, particularly in the Navy Oceanographic Office and the Research Flight Facility, lay in the comparison of the infrared radiometers and the absorption hygrometers of the two aircraft. It is sad to say that neither of these comparisons could be made

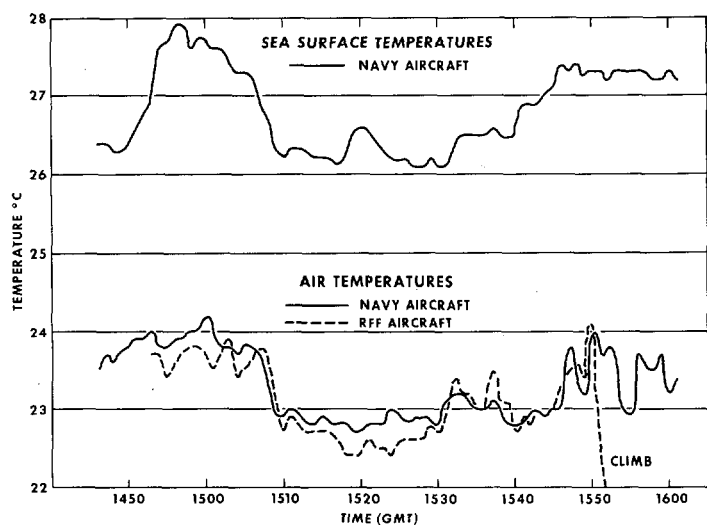


FIGURE 2.—Sea surface temperatures as measured by Navy ART and air temperatures as measured by both aircraft on Cape Kennedy to USCGSS Peirce leg of the flight.

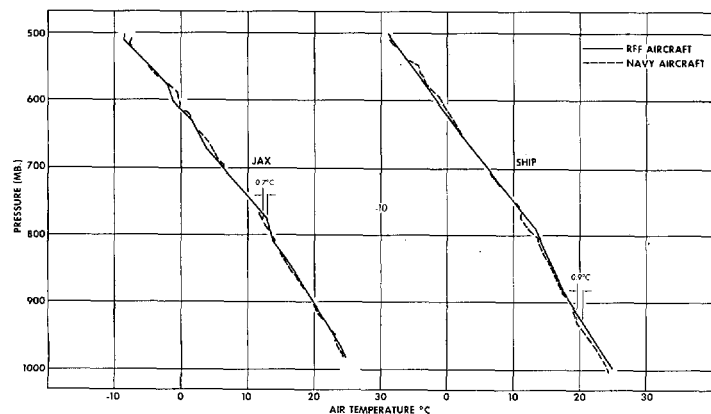


FIGURE 3.—Comparison of air temperature profiles measured by both aircraft.

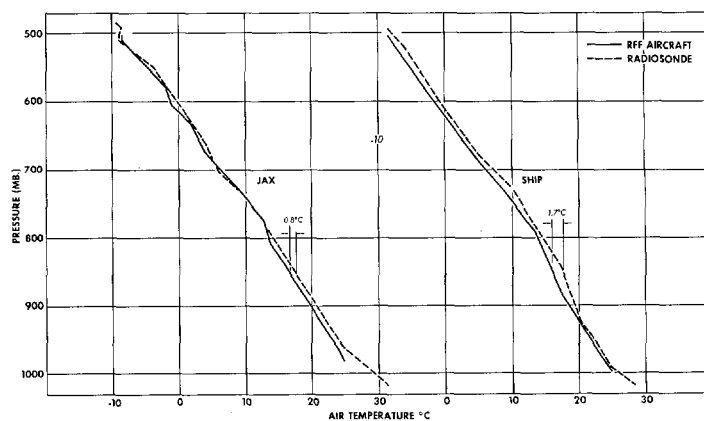


FIGURE 4.—Comparison of radiosonde temperature profile with RFF aircraft profile.

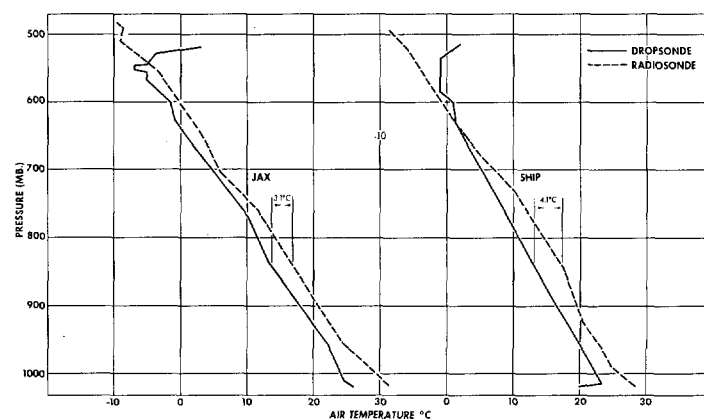


FIGURE 5.—Comparison of radiosonde and dropsonde temperature sounding.

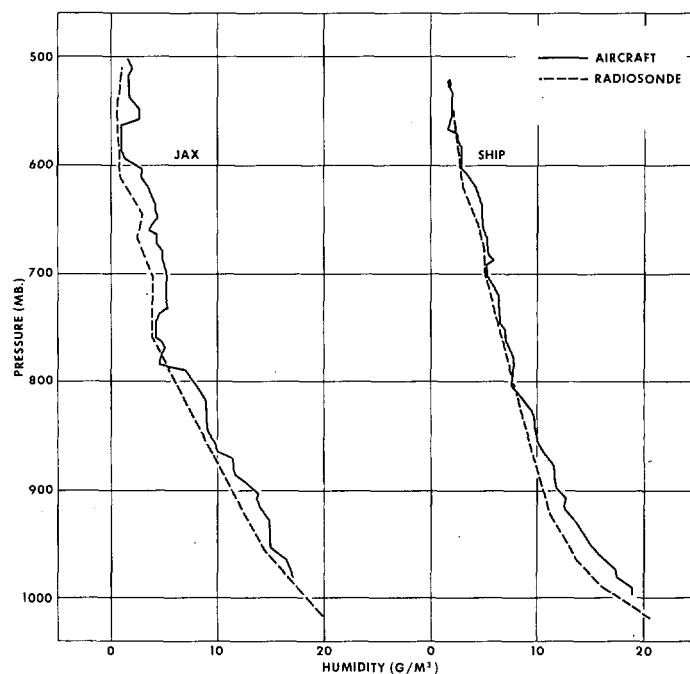


FIGURE 6.—Comparison of RFF aircraft and radiosonde humidity sounding.

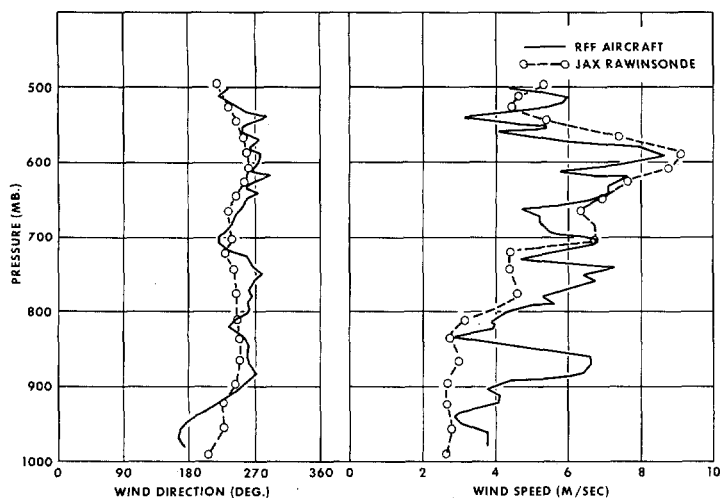


FIGURE 7.—Doppler determined wind direction and speed compared with rawinsonde data at Jacksonville, Fla.

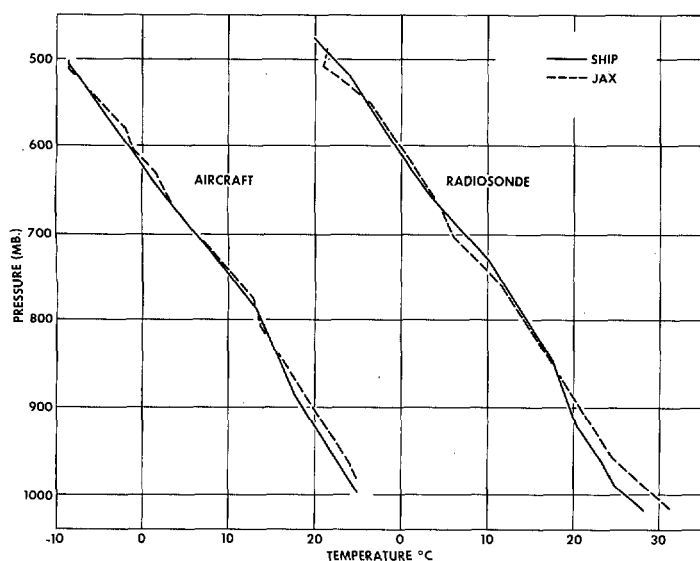


FIGURE 8.—Aircraft temperature profiles for the two stations compared with the radiosonde profiles.

because of the malfunction inflight of one of these systems on each aircraft. The Barnes IT-2 radiometer failed only moments after crossing the coastline just north of the Cape and could not be repaired aboard the plane. On the other hand, the infrared hygrometer on the Navy plane malfunctioned shortly after takeoff and its ailment was not diagnosed until the Constellation returned to its home base at Patuxent River, Md. The Navy plane has a backup system for humidity measurements—part of the AMQ-17 system described earlier—but it was not operational that day. Thus, no humidity measurements were obtained by this group. The RFF had no backup IR unit for its aircraft and thus sea surface temperatures were not obtained by that group.

Comparisons of certain aircraft sensors with an early version of SAIL's boundary layer instrument package and

of the Navy ART and *Peirce* bucket sea surface temperatures are shown in the table. Here, plane-to-plane comparisons of air temperature are excellent and plane-to-boundary layer package comparisons are reasonably good for the Navy's 1,000-ft. passes and very good for the 500-ft. passes of both airplanes. The humidity data are not too comparable, and the fluctuations by the amounts shown for the boundary layer package for the 1-min. intervals between measurements indicate that part of the difference may have been a result of relative humidity measurement errors in the package sensor. The IR sea surface temperature readings certainly are within the $\pm 0.4^{\circ}\text{C}$. accuracy figure quoted by the Navy.

Figures 3 through 5 show the results of the vertical profiles of air temperature obtained by the aircraft, radiosondes, and dropsondes over the ship and at Jacksonville. Certainly one must agree that the aircraft comparisons are the best of the lot, although a large part of the differences observed in the aircraft-radiosonde comparisons can be rationalized away. The fact that the radiosonde readings over the ship are consistently higher than the aircraft readings might be attributed to trouble in obtaining a baseline check aboard the ship, as was indicated by one of the scientists making the launch. The excellent comparison at Jacksonville was obtained even though the radiosonde was launched at the airport and the aircraft profile was made several miles offshore or a total distance of about 20 n.mi.

The dropsonde-radiosonde comparisons of air temperature are so poor that figure 5 really should not receive further comment. The large observed differences may be attributed to calibration errors or improper baseline checks for the dropsonde, although it seems unreasonable that these errors would have caused the odd shapes of the dropsonde soundings. Whatever the cause, the fact that one unit was 12 yr. old and the other 14 yr. old probably did not help the situation. At any rate this comparison should be made again with newer equipment.

The humidity profiles shown in figure 6 are given as absolute humidity (gm./m.^3). For the radiosonde, absolute humidity was computed from the temperature and relative humidity data, thus presenting a possible double source of error. The 2- to 3- gm./m.^3 differences observed in the soundings could be a result of temperature and relative humidity errors in the radiosonde and/or some error in the infrared hygrometer system on the aircraft. Again, it was unfortunate that the second hygrometer system was not available.

Because of the large differences between the radiosonde and dropsonde air temperatures and the use of this parameter along with relative humidity to compute absolute humidity, no comparison was made of the humidity data from these two sources. Possibly a future experiment will permit such a comparison.

The comparison of the Doppler wind system aboard the RFF DC-6 with the winds-aloft data from the Jacksonville rawinsonde are shown in figure 7. Generally, for wind

direction the agreement above the 920-mb. level is reasonably good, the observed differences at most points being within the accuracy limits quoted for the Doppler system. This system, however, shows rapid fluctuations in wind speed throughout the profile whereas the rawinsonde data have a smoothed appearance. This, of course, is due to the fact that individual point readings for rawinsonde wind data represent layer averages while Doppler readings are instantaneous values.

4. CONCLUSIONS

What do these results mean in terms of air-sea interaction studies? Surely, one recognizes that a more uniform region, in terms of atmospheric parameters and oceanic thermal conditions, places much more stringent requirements on instrumental accuracies than an area where there are large horizontal gradients of temperature and moisture. One also realizes that accuracy requirements are much greater where single samples are used as opposed to the cases where many samples are averaged. With respect to this experiment these considerations can be applied to the comparison shown in figure 8. Here is shown a comparison of the vertical profiles of air temperature at the ship and at Jacksonville, Fla., as obtained in one case by the RFF aircraft and in the other case by radiosonde measurements. Such a comparison could be made because the ship and Jacksonville happened to fall on a line essentially parallel with the wind trajectory (see fig. 7).

There are a couple of things worth noting in this figure. First, for practically the whole of both soundings the observed differences between the Jacksonville station and the ship station are so small that they might represent instrumental inaccuracies rather than air temperature changes. Second, note that for the layer between 660 and 830 mb. the aircraft soundings show almost no net change in temperature while the radiosonde

soundings show a significant temperature increase. Thus for an environment such as was found east of Jacksonville in June, instrumental accuracies would be of major concern.

It is fair to conclude from the results, then, that aircraft and radiosonde measured air temperatures, and possibly humidities also, were within the accuracies stated for the sensors. Another look at the dropsonde should be taken before it is accepted for air-sea interaction studies. A further development of SAIL's boundary layer instrument package should provide more accurate instrumentation for boundary layer research.

Again, it is emphasized that this experiment was primarily intended to show what the available instruments could do. Whether they will be suitable for the ocean-atmosphere interaction investigations now being planned must await studies of the environment in which the experiments are planned.

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